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The Russia-Saudi Arabia oil price war during the COVID-19 pandemic

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ABSTRACT

The COVID-19 pandemic damaged crude oil markets and amplified the consequences of uncertainty stemming from the Russia-Saudi Arabia oil price war in March-April of 2020. We investigate the impacts of the oil price war on global crude oil markets. By doing so, we use the daily futures and spot prices in three major crude oil markets – West Texas Intermediate, European Brent, and Oman – to perform a systematic analysis of the impacts of the oil price war on them. The event study method, a well-established analytical tool to measure the impacts of a given event on markets, is used in this study. The results indicate that information leakage plays an important role in the impacts of the price war. The outbreak of and truce following the price war have asymmetrical impacts on the markets; negative impacts generated by information leakage during the outbreak are generally more durable than the positive ones it generated during the truce. Furthermore, the magnitude of the impacts on futures markets is negatively correlated with the time-to-maturity of futures. Finally, negative crude oil prices affect West Texas Intermediate crude oil markets the most. Our findings generally show that market participants could perceive and assimilate market changes and adjust their expectations, which restrained the impacts that should have occurred within the oil price war.

1. Introduction

Crude oil markets have witnessed structural changes since March 2020, when the COVID-19 pandemic spread widely. Containment measures reduced people's outdoor activities and severely impacted tourism, airlines, and shipments; as a result, the demand for oil products declined dramatically. The abrupt drop in demand as a result of the continuous deterioration of the COVID-19 pandemic led to crude oil supplies that exceeded the level market fundamentals would determine, resulting in a glut of crude oil and a sharp price fall. What followed was a massive increase in inventory and limited storage capacity, with prices plunging so fast that they triggered a historic negative crude oil price. Meanwhile, futures markets also witnessed a deep contango, and pushed the cost-of-carry extremely high.

Amid the turmoil of crude oil markets, an oil-related geopolitical conflict between Saudi Arabia and Russia – the Russia-Saudi oil price war – is remarkable. Saudi Arabia, with its allies in the Organization of Petroleum Exporting Countries (OPEC), proposed a production cut in early March 2020 in order to stabilize crude oil markets. However, this action was met by a challenge from Russia – an oil giant outside the OPEC – whereby it would increase its production and supply. Saudi Arabia responded with an increase in oil production and Russia retaliated in the same way, which resulted in the oil price war. Through broad international political mediation and intervention, Russia and Saudi Arabia finally reached a cut agreement in April 2020. The oil price war and the pandemic severely damaged crude oil markets, which put huge downward pressure on prices and negatively affected the welfare of oil producers. In addition, the oil price war also resulted in some surprising structural changes to crude oil markets and challenged the crude oil pricing system (Fattouh and Imsirovic, 2020); these side effects are likely to last longer in the current volatile international political and strategic environment (Singh, 2020). Identifying the impacts of the oil price war on global crude oil markets during the COVID-19 pandemic is vital for energy managers and analysts in both the public and private sectors.

The relationship between oil producers has been analyzed in previous studies (e.g., Ansari, 2017; Behar and Ritz, 2017; Bradshaw et al., 2019; Klein, 2018; Parnes, 2019; Plante, 2019; Ratti and Vespignani, 2015), some of which primarily focus on how they interacted during

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the U.S. shale oil revolution. Ansari (2017) attributes OPEC's failure to cut oil production when it faced a price drop in 2014 to the desire to defend its market share. Bradshaw et al. (2019) analyze the roles of Saudi Arabia and Russia in the new oil order under future cleaner production. However, few have paid attention to the impacts of extreme events, such as war, disease/pandemic, natural disasters, and terrorism, on global markets (e.g., Karali et al., 2019; Ramiah et al., 2019). For instance, Karali et al. (2019) use an event study to measure how crude oil markets reacted to 10 influential events over a 25-year period. Ramiah et al. (2019) investigate how terrorist attacks affect risk and return in commodity markets using an event study. It is noteworthy that some recent research has focused on energy markets during the pandemic (e.g., Corbet et al., 2020; Singh, 2020). For example, Corbet et al. (2020) focus on comovements and volatility spillovers between oil and renewable energy firms during the pandemic and consider the negative crude oil price, as well as positive and economically meaningful spillovers from oil to renewable markets.

The COVID-19 pandemic and the oil price war have been catastrophic for crude oil markets, and this renders our questions crucial: Did the Russia-Saudi Arabia oil price war affect global crude oil markets in the short term? If it did have an effect, what is the magnitude of the impacts and what are the characteristics of those impacts? Furthermore, did market participants perceive or predict what the markets would be like before the war broke out or after it ended – in other words, was there information leakage in the markets?

In addressing these questions, the event study method, a well-established analytical tool to measure the impacts of a given event on markets, is adopted in this study. The underlying assumption is that the market processes information related to events in an efficient and unbiased manner (Fama et al., 1969). The important advantage of using the event study method is that we can construct the measurement of Russia-Saudi Arabia oil price war's economic impact using the returns of crude oil futures prices and spot prices observed over a short time span (MacKinlay, 1997). Thus, the event study method has been widely used to measure how markets respond to events in the short term, such as energies (e.g., Demirer and Kutan, 2010; Karali et al., 2019; Ramiah et al., 2019; Sabet and Heaney, 2016); equities (e.g., Aitken et al., 1998; Lane and Jacobson, 1995; Lyon et al., 1999; Yang et al., 2015); and marketing (e.g., Chen et al., 2012; Swaminathan and Moorman, 2009; Wiles and Danielova, 2009). As for the dataset, we use the daily futures and spot prices of three major crude oil markets (i.e., West Texas Intermediate (WTI), European Brent, and Oman) to analyze how two events, the outbreak and truce (end) of the price war, influenced global crude oil returns. To investigate how they affect the markets in different horizons, four futures prices are considered with various time-to-maturity: nearby and third-, sixth-, and twelfth-deferred futures.

Our findings indicate that information leakage indeed exists and plays an important role in the impacts generated by the price war. Specifically, considering 2-day information leakage, nearby futures returns reduced by 42.58% on average within 6 trading days after the war started. When 5-day information leakage and the negative price are considered, nearby crude oil futures return decreased by 179.80% on average within 7 trading days after the war ended. In futures markets, the magnitude of the impact is negatively correlated with the time-to-maturity of the futures; that is, deferred futures suffer from fewer impacts than nearby futures. With regard to spot markets, the spot return drops by 48.97% on average within 6 trading days after the outbreak, with 2-day information leakage considered, and a huge fall of 175.34% within 7 trading days after the truce with 5-day information leakage and the negative price jointly considered. Furthermore, for the negative crude oil price, we find that it does not have a statistically significant effect on the markets jointly, but it significantly influences WTI crude oil markets; this can be attributed to inflexible delivery procedures and fear related to physical delivery. Our results reveal that in general, market participants in crude oil markets could perceive and assimilate some information and adjust their expectations of the markets, which restrains impacts that should have happened within the oil price war. Furthermore, the outbreak and truce influenced the markets asymmetrically, and negative impacts generated from information leakage during the outbreak are generally more durable than the positive ones it generated during the truce. The oil price war resulted in a huge shock to the energy sector, and we also discuss some of the implications.

This paper makes the following contributions to the literature. First, to the best of our knowledge, it is the first to analyze how the Russia-Saudi Arabia oil price war influenced crude oil markets using an event study approach. Second, we use different price series that consider nearby futures as well as third-, sixth-, and twelfth-deferred futures to investigate whether they reacted to the price war in different ways. These deferred futures could allow us to evaluate the impacts of the oil price war in a one-year-forward horizon. Third, we provide evidence on information leakage in global crude oil markets during the price war. Market participants were able to perceive and assimilate new information about the outbreak and truce during the price war.

The rest of the paper is structured as follows. Section 2 discusses the background of the price war and some relevant literature on the event study analysis. We illustrate the methodologies of the event study approach in Section 3. Section 4 presents the data and conducts a preliminary analysis. Empirical results are reported in Section 5. Section 6 concludes and discusses implications and directions for future research.

2. Background and Russia-Saudi Arabia oil price war

2.1. Background

Global crude oil markets have witnessed sluggish demand since March 2020. Virus containment has been in effect to reduce the spread of the novel coronavirus (SARS-CoV-2) in many countries, which reduced driving and restricted some transportation services. Thus, rail, freight, and air industrial sectors suffered heavily, and the demand for gasoline, diesel, and jet fuel decreased significantly. According to the U.S. Energy Information Administration (EIA), the consumption of gasoline dropped by 46.40% from 9,449 to 5,065 thousand barrels per day since early March to early April 2020, which is the largest decline in a month historically. When oil demand, which is extremely inelastic, dried up, even tiny amount of crude oil pushed into the market would have resulted in a dramatic price fall. For instance, the WTI futures price had traded in a range of roughly $50-$60 per barrel since January 2019 without presenting large variability. However, in March 2020, when the pandemic was widespread globally, the price started to collapse fast, from about $50 per barrel to a level of $30 per barrel in only one month. A similar pattern could be observed in other crude oil markets as well. The glut of crude oil has also filled much of the available storage capacity, and especially in Cushing, Oklahoma, which is a major U.S. storage location. Based on EIA data, weekly U.S. total commercial crude oil inventories increased by 16.79% (75 million) from early March to the end April 2020. Also, until the end April 2020, U.S. net crude oil inventories in each region almost reached or exceeded half the storage capacity, with significant increases witnessed on the Gulf Coast and in Cushing, Oklahoma (EIA, 2020b).

Sluggish demand plus storage limits for crude oil changed the term structure of crude oil futures as well, in which a huge contango has been present since the outbreak of the pandemic in March 2020. Furthermore, the term structure is associated with arbitrages through calendar spreads between different futures contracts. Before the pandemic, a backward (inverted) crude oil market was frequently observed.[1] Backwardation, in practice, means that contract prices decrease with the

[1] Further quantitative analyses are presented in Section 4.

time-to-maturity going far in terms of a trading day. It usually occurs when the market supply does not meet market demand and storage levels are relatively low, and convenience yield – i.e., the benefit of holding physical storage rather than futures contracts – could exist theoretically in order to meet unexpected demand or adjust production schedules. However, contango is the reverse of backwardation and contract prices go up with the time-to-maturity going far in terms of a trading day. The contango motivates market players to purchase crude oil in the spot market at a low price and store it for a future delivery (selling) with a deferred contract that has been shorted. Thus, inventory is likely to go up when the market is in contango generally. Theoretically, market participants could have stored crude oil for future delivery, and this may have been the case when storage was not so limited. However, trading involves physical delivery is generally more costly than closing out positions directly; also, storage capacity became more limited during the pandemic, which pushed the cost-of-carry upward – though the interest rate could remain low enough. Hence, these factors are not likely to incentivize buyers to pick up crude oil. Regardless of whether the high deferred futures price could compensate the cost-of-carry or long traders could have benefited if they had stored the crude oil and delivered later, the storage limits and some logistics problems during the pandemic may generate many uncertainties, which reflects that liquidating contracts through physical delivery during the pandemic was problematic; this may also be a factor that triggers some extreme phenomena, such as the negative price (Fattouh and Imsirovic, 2020).

Along with the structural changes in fundamentals, what greatly surprised the markets was the historic negative price, though this is still a possibility for storable commodities, and especially when demand dries up. On April 20, 2020, the New York Mercantile Exchange (NYMEX) May contract (ticker: CLK20) futures price for WTI fell below zero and went into negative territory for the first time since the trading of WTI futures contracts began in 1983. The negative crude oil price reveals that the market has difficulty in closing out positions in such extreme conditions, and in effect traders pay their counterparties to liquidate (EIA, 2020a). In addition, a negative price also reflects oil firms' need to rent tankers to store surplus supply (Corbet et al., 2020). The presence of negative prices can largely be attributed to fear regarding physical delivery and high storage costs. April 20, 2020 was the next to last trading day of the WTI May futures contract (April 21, 2020), and traders who were not willing to physically deliver needed to liquidate their contracts before the expiration date. Moreover, according to the WTI contract's specification, delivery of the crude oil must occur at a pipeline or storage facility in Cushing, Oklahoma (EIA, 2020a), which restricts where the delivered crude oil can be stored. As stated previously, the glut of crude oil has led to a huge bottleneck of crude oil-constrained storage and sharply rising storage costs. Hence, traders who intended to store crude oil may face an inelastic demand for crude oil in storage locations such as Cushing, and thus a small oil inflow would result in a large change in the quantity demanded. The limited storage capacity put extreme pressure on traders who needed to liquidate their contracts and rendered physical delivery even less possible, since WTI crude oil is landlocked. The fear of physical delivery spread across the market and resulted in a long squeeze, which put lots of downward pressure on the market price and heavily consumed market liquidity. Indeed, many traders left the market on that day. Indeed, the open interest, defined as the number of outstanding futures contracts, declined by 87.99%, from 108,593 to 13,044 contracts on April 20, which was the largest plunge over the life of the May 2020 contract. On April 21, 2020, the WTI May crude oil contract futures price returned to positive territory and finally settled at around $10 per barrel. The negative price was indeed a big market surprise and may epitomize some of the challenges and weaknesses of futures pricing. For instance, long traders generally seemed to be inexperienced in taking physical delivery and were likely to exacerbate the price as they rushed to close out their positions (Fattouh and Imsirovic, 2020).

2.2. Russia-Saudi Arabia oil price war

Before the oil price war, Saudi Arabia and Russia had cooperated successfully in facing the challenge of the U.S. shale oil revolution since 2016, and created an informal alliance called OPEC+ (13 OPEC members and 10 non-OPEC members) in December 2016. This cooperation defended the market shares of both Russia and OPEC countries and the crude oil price increased, fluctuating at around $60 per barrel from early 2019 to early 2020. The price war began in March 2020 when Russia refused to cut oil production in response to plummeting demand and Saudi Arabia retaliated by also increasing production. Since the COVID-19 pandemic had created a glut of crude oil in global markets, OPEC initiated the 178th (Extraordinary) Meeting of the Conference on March 5, 2020, in Vienna, Austria. At this meeting, OPEC agreed to cut oil production by an additional 1.5 million barrels per day through the second quarter of 2020. The organization called on Russia and other non-OPEC producers to participate in the cut initiative (OPEC, 2020b). However, on March 6, 2020, Russia announced its refusal and WTI and Brent crude oil prices fell by 10% (BBC, 2020b). This threatened the cooperation that OPEC+ set up in December 2016 to jointly stabilize the crude oil markets (Singh, 2020).

Saudi Arabia's retaliation came on March 8, with an announcement of price discounts of $6 to $8 per barrel to customers in the U.S., Europe, and Asia. On March 10, Saudi Arabia announced a bold plan whereby it would increase its production from 9.7 million barrels per day to 12.3 million from April 2020 (Singh, 2020); Russia responded with a plan to increase crude oil production by 0.3 million barrels per day (Guardian, 2020). The global crude oil price declined more severely, from about $50 per barrel to roughly $10 per barrel, and fluctuated in this level until the end of March. On April 2, after Saudi Arabia and Russia had been engaged in the price war for almost a month, U.S. President Donald Trump called Saudi Arabian crown prince and de facto ruler Mohammed bin Salman and threatened to withdraw U.S. military support if OPEC countries and their allies did not reduce crude oil production (this was a turning point Reuters, 2020). The next day, Saudi Arabian foreign and energy ministers publicly criticized the Russian government for refusing to participate in the OPEC+ cut agreement (Bloomberg, 2020). Russia then prepared for an extraordinary OPEC meeting to negotiate some issues related to cutting production, and issued an official statement that it would cut crude oil production by 10 million barrels per day (FT, 2020). On April 9 at the 9th (Extraordinary) OPEC and non-OPEC Ministerial Meeting, Russia agreed that it would do that (OPEC, 2020a), and the Russia-Saudi Arabia oil price war ended.

Since some related events occurred before and after the oil price war, we define the date of the outbreak as March 10, 2020, and the corresponding date of the truce as April 9, 2020. It is obvious that the oil price war lasted for about one month, accompanied by a rapid surge in daily global COVID-19 cases from about 5,000 to over 86,000 during this period, according to data from the coronavirus resource center at Johns Hopkins University. Table 1 shows the timeline of the price war (including some pre- and post-events). Again, to simplify our analysis, we set the start date of the price war as March 10, 2020 and the end as April 9, 2020. The former is the date the oil production increase began in both Saudi Arabia and Russia and the latter is when Russia agreed to cut oil production.

3. Methodologies

The event study approach is a widely applied analytical tool to investigate the effects of various events on markets or corporations (Demirer and Kutan, 2010). It is based on the efficient market hypothesis (EMH), which assumes that futures prices can incorporate new information quickly, since traders continually re-evaluate the value of futures contracts (Pozo and Schroeder, 2016). We evaluate two events of the oil price war: the outbreak and truce (end, or post-war). For the

Table 1
Timeline of Russia-Saudi Arabia oil price war (including pre- and post-events).

Date	Description
March 5, 2020	The OPEC held the 178th (Extraordinary) Meeting of the Conference and agreed to cut oil production and called Russia and non-OPEC producers abide the OPEC decision. (OPEC, 2020b)
March 6, 2020	Russia refused to agree the OPEC's production cut decision. (BBC, 2020b)
March 8, 2020	Saudi Arabia retaliated and announced unexpected price discounts of \$6 to \$8 per barrel to customers in the U.S., Europe, and Asia. (Singh, 2020; Guardian, 2020)
March 10, 2020	Saudi Arabia announced that it would increase its production from 9.7 million/bpd to 12.3 million/bpd. Russia fought back with a plan to increase crude oil production by 0.3 million/bpd. (Singh, 2020; Guardian, 2020)
April 2, 2020	U.S. President Donald J. Trump threatened Saudi Arabia with withdrawal of the U.S. military support if the OPEC and its allies did not reduce crude oil production. (Reuters, 2020)
April 3, 2020	Saudi Arabian foreign and energy ministers criticized Russia government for refusal to take part in the OPEC+'s agreement. (Bloomberg, 2020)
April 9, 2020	Russia agreed to reduce its production by 10 million barrels per day at the 9th (Extraordinary) OPEC and non-OPEC Ministerial Meeting. (FT, 2020)
April 12, 2020	The 9th (Extraordinary) OPEC and non-OPEC Ministerial Meeting emphasized the important and responsible decision to adjustment production that agreed. (OPEC, 2020a)

outbreak of the price war, the event date ($t = 0$) is March 10, 2020, when Saudi Arabia announced it would increase its oil production from 9.7 million/bpd to 12.3 million/bpd. The second event, the truce, occurred on April 9, 2020, when Russia agreed to reduce oil production and the oil price war ended.

Following Pozo and Schroeder (2016), we apply event study analysis by first specifying the obtained events timeline, in which the total number of observations T is divided into two subsamples: estimation window ($t \in [T_1 + 1, T_2]$) and event window ($t \in [T_2 + 1, T_3]$). It is obvious that the estimation window ends before the start of the event window. In this study, the estimation window consists of 253 trading days' observations – approximately one trading year – prior to the earliest event window. Specifically, the estimation window for the outbreak spans from the date when $t = -255$ to the date when $t = -3$, while the estimation window for the truce spans from the date when $t = -258$ to the date when $t = -6$.[2] We should note that the estimation window of the truce consists of the period of the outbreak, which reveals that we measure what occurs in the markets after market participants have experienced and assimilated what happened after the war started. Since crude oil is one of the most actively traded commodities and Saudi Arabia and Russia are two powerful crude oil producers globally, their pre-war responses and strategies are helpful for market participants. Hence, market participants likely anticipated what would happen in the future if a price war occurred, which indicates that they may perceive and assimilate new information. Thus, we hypothesize that there was information leakage before the price war. To test this hypothesis, we should specify multiple event windows of different widths. A similar method is used by Pozo and Schroeder (2016), who argue that various window widths are capable of evaluating and comparing market reactions in different event windows. The overall specification of our event study is shown in Fig. 1. Selection of the event windows is based on some notable points during the oil price war, which is likely to influence the expectations of market participants. For the outbreak, the longest event window starts 2 trading days before the outbreak; that is March 6, 2020 ($t = -2$), when Russia declined to agree to OPEC's production cut decision. This could be a point at which market participants adjusted their expectations, some of whom may believe that the crude oil supply cannot respond to sluggish demand accordingly; this would worsen the bearish markets, urging traders to exit the market to avoid potential losses. We specify the other three event windows by changing the starting points from March 6, 2020 ($t = -2$) to March 11, 2020 ($t = 1$), and they all end on March 31, 2020 ($t = 15$). In the case of the truce, the longest event window starts 5 trading days before the event date; that is April 2, 2020 ($t = -5$) when the U.S. asked Saudi Arabia and its allies to arrive at an agreement about a production cut. Similarly, market participants were likely to adjust their expectations, some of whom might wait and see how the markets were going on and hold onto their preexisting trading strategies rather than leaving the markets quickly. We also specify 6 other event windows by varying the starting dates from April 2, 2020 ($t = -5$) to April 13, 2020 ($t = 1$); all end on April 30, 2020 ($t = 15$). It should be noted that we use the event window with a maximum length of 15 trading days after the event date. The main reasons are as follows. First, the event study method relies on prediction methods, thus the accuracy of results is expected to decrease over time. Second, the probability of having other events influencing price behavior is higher in a longer event window (Pozo and Schroeder, 2016).

The impacts generated by the events are assessed by estimating abnormal returns. For crude oil market i, the abnormal return (AR) is

$$AR_{it} = R_{it} - E\left[R_{it} | I_t\right], \tag{1}$$

where R_{it} denotes the realized returns on the crude oil market i at time t, and $E\left[R_{it} | I_t\right]$ is normal returns predicted by the information set I_t without an event being at work. Logarithmic returns are calculated as the log-difference between two consecutive daily prices, i.e., $\log\left(op_t\right) - \log\left(op_{t-1}\right)$, where op_t is the crude oil price at time t. Considering the negative crude oil prices triggered in WTI crude oil markets on April 20, 2020, their log-return cannot be calculated because the domain of the logarithm function is all positive real numbers. Hence, we apply the one-period simple returns for the negative crude oil prices, as $\left(op_t - op_{t-1}\right)/op_{t-1}$, the percentage change in two consecutive daily prices. To ensure all of the returns calculated can be realized historically, we should note that when a futures contract expires on day d, and needs to be rolled over to a deferred futures, we compute the return for day $d + 1$ as the logarithmic difference or percentage change in the deferred futures price between day $d + 1$ and day d, rather than the "roll yield", which is the difference in futures prices across contracts on the rolling day (Bessembinder, 2018).[3] According to Bessembinder (2018), traders do not earn or pay the roll yield, and all gains and losses on futures positions only depend on the price changes of individual contracts. Specifically, the return on day $d + 1$ is

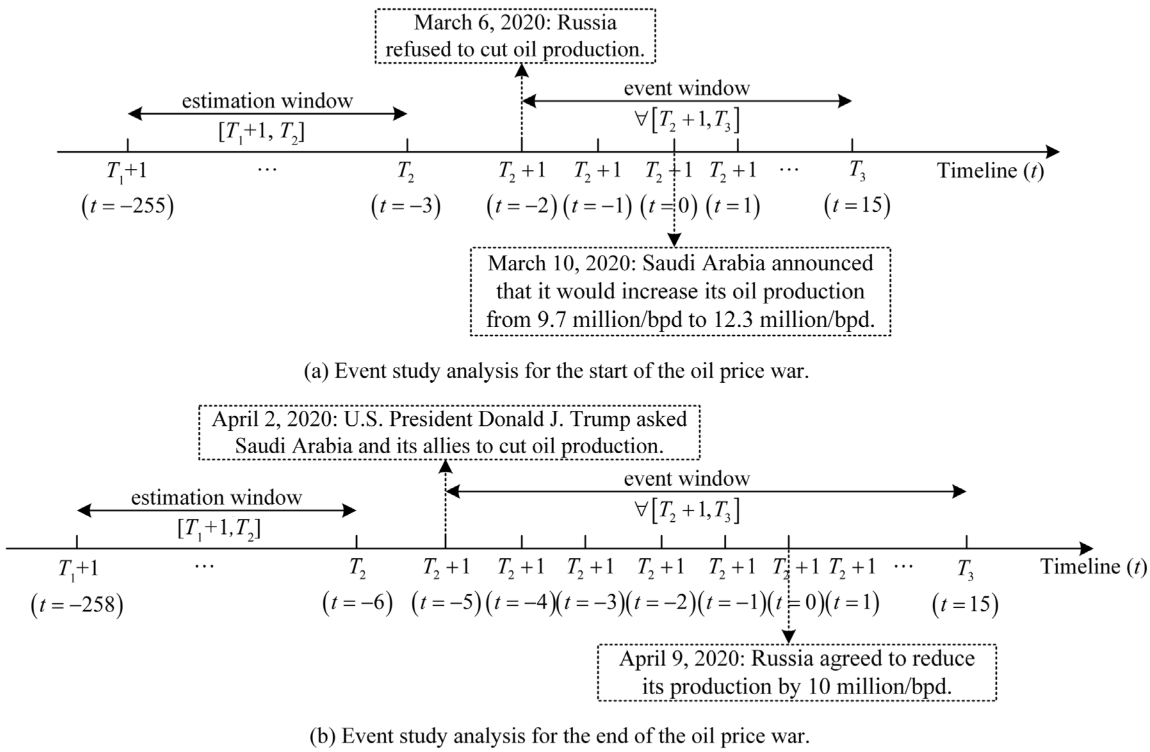
$$r_{d,d+1} = \log\left(F_{2,d+1}\right) - \log\left(F_{2,d}\right), \tag{2}$$

or

$$r_{d,d+1} = \frac{\left(F_{2,d+1} - F_{2,d}\right)}{F_{2,d}}, \tag{3}$$

[2] We also conduct an alternative event study analysis with an estimation window that includes 506 trading days' observations (i.e., $t = -508$ to $t = -3$ for the outbreak, and $t = -511$ to $t = -6$ for the truce). The results are generally similar. We thank an anonymous reviewer for this suggestion.

[3] We also conduct an alternative event study analysis without considering roll yields when rolling over the futures contracts, and the main results are generally similar.



(a) Event study analysis for the start of the oil price war.

(b) Event study analysis for the end of the oil price war.

Fig. 1. Event study analysis for the oil price war. *Notes*: The estimation window is defined as $[T_1 + 1, T_2]$, and the event window is defined as $[T_2 + 1, T_3]$. For the outbreak of the oil price war, the estimation window spans from the date when $t = -255$ to the date when $t = -3$ with a total of 253 trading days' observations, approximately one trading year. The event date is March 10, 2020 ($t = 0$), and the event window starts on March 6, 2020 ($T_2 + 1$) and stretches to March 31, 2020 (T_3). For the truce of the oil price war, the estimation window spans from the date when $t = -258$ to the date when $t = -6$ with a total of 253 trading days' observations. The event date is April 9, 2020 ($t = 0$), and the event window starts on April 2, 2020 ($T_2 + 1$) and stretches to April 30, 2020 (T_3).

where $F_{2,d}$ and $F_{2,d+1}$ denote deferred futures prices on days d and $d + 1$, respectively. It should be noted that the individual futures contract – that is F_2 – is used to calculate the return. However, if we ignored the roll yield, the return on day would be calculated as $r_{d,d+1} = \log\left(F_{2,d+1}\right) - \log\left(F_{1,d}\right)$ or $r_{d,d+1} = \left(F_{2,d+1} - F_{1,d}\right)/F_{1,d}$, and traders do not earn this kind of return on that day.

We employ a revised market model to estimate normal returns. Generally, the market model uses an overall market index as a proxy to predict normal returns, then evaluate deviations between realized returns and normal returns; this method is explicit and relatively easy to use. Hence, it is widely used as a benchmark to assess abnormal returns in financial economics (e.g., Black and Kim, 2012; Brown and Warner, 1985; Demirer and Kutan, 2010; Draper, 1984; O'hara and Shaw, 1990; Pozo and Schroeder, 2016; Zhu et al., 2020). For instance, in terms of commodity markets, Demirer and Kutan (2010) use an event study with a standard market model to measure how crude oil spot and futures prices react to OPEC and U.S. Strategic Petroleum Reserve (SPR) announcements. Their findings indicate that only the OPEC cut announcements yield significant impacts and the use of the SPR initiates a short-run market reaction. With regard to equity markets, Pozo and Schroeder (2016) employs a standard market model with autoregressive distributed lag specification to measure the costs of meat and poultry recalls to food firms. They find that stock returns are reduced by 1.15% within five days after a food firm is involved in a recall with a serious food safety hazard. In our context, the standard market model is limited, since it does not completely consider the conditional heteroskedasticity that generally exists in term-series data. Hence, following Deaves and Krinsky (1992), we employ a market model with a generalized autoregressive conditional heteroscedasticity (GARCH) specification whose lag orders are all one[4]:

$$R_{it} = \alpha_i + \beta_i R_{mt} + \varepsilon_{it}, \text{for } \forall t \in \left[T_1 + 1, T_2\right], \tag{4}$$

and

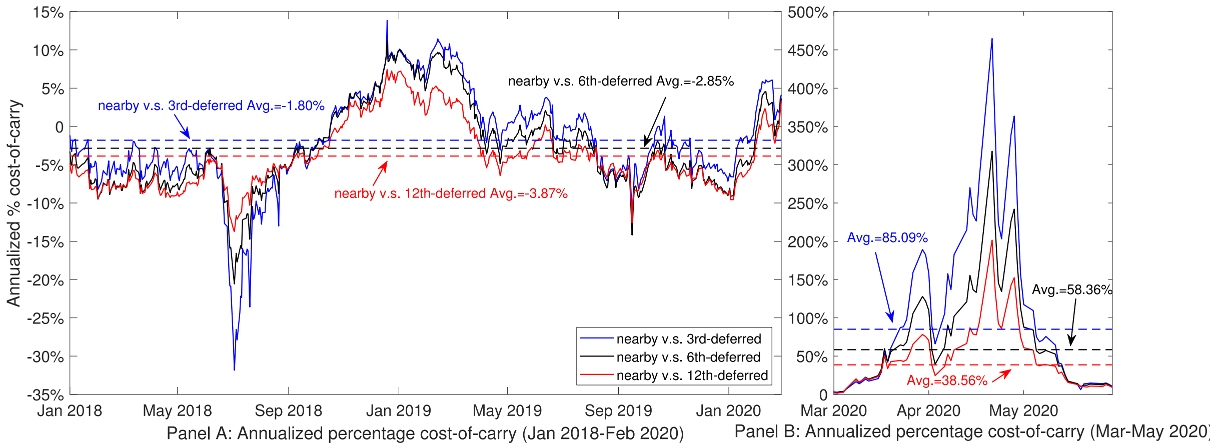
$$\begin{aligned} &\varepsilon_{it} = \theta_{it}\varepsilon_{i,t-1} + \eta_{it}, \\ &\eta_{it} = \varepsilon_{it}/\sqrt{h_{it}}, \\ &h_{it} = \omega_i + \gamma_i\varepsilon_{i,t-1}^2 + \delta_i h_{i,t-1}, \varepsilon_t | I_{t-1} \sim N\left(0, h_t\right), \end{aligned} \tag{5}$$

where R_{mt} is the return of the market index at time t; α_i and β_i are parameters that need to be estimated in each crude oil market i. In terms of the GARCH (1,1) specification, I_{t-1} is the information set at time $t-1$. The conditional distribution of error term ε_t is zero mean with the variance h_t. η_t is the standardized residual. Motivated by Ramiah et al. (2019), we use the MSCI ACWI index, which is further discussed in Section 4. Then normal returns are predicted as

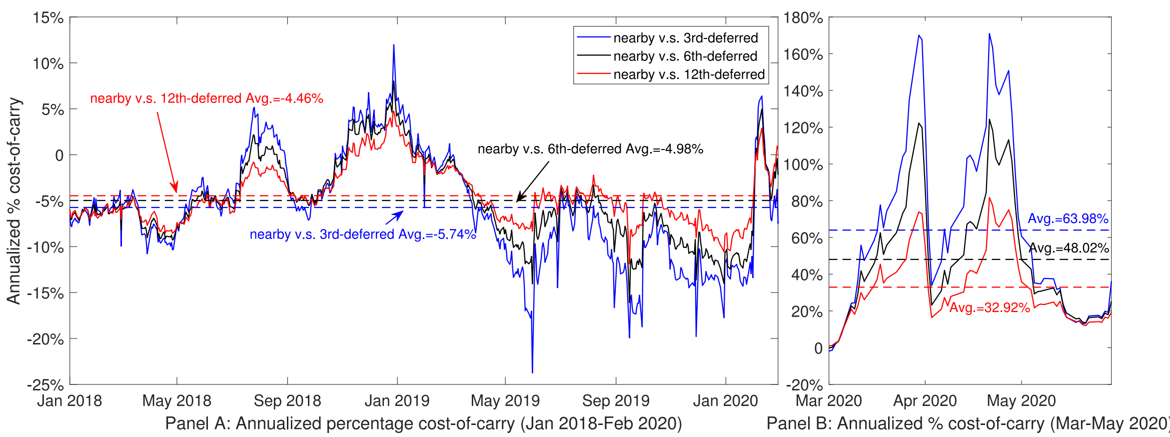
$$E\left[R_{it}|I_t\right] = \hat{\alpha}_i + \hat{\beta}_i R_{mt}, \text{for } \forall t \in \left[T_2 + 1, T_3\right]. \tag{6}$$

To evaluate the impacts generated by the event overall, it is necessary to aggregate obtained abnormal returns (ARs), whereby we adopt the cumulative abnormal return (CAR) in this study. For market i, the CARs calculated over a time interval $\left[\tau_1, \tau_2\right]$ are specified as the

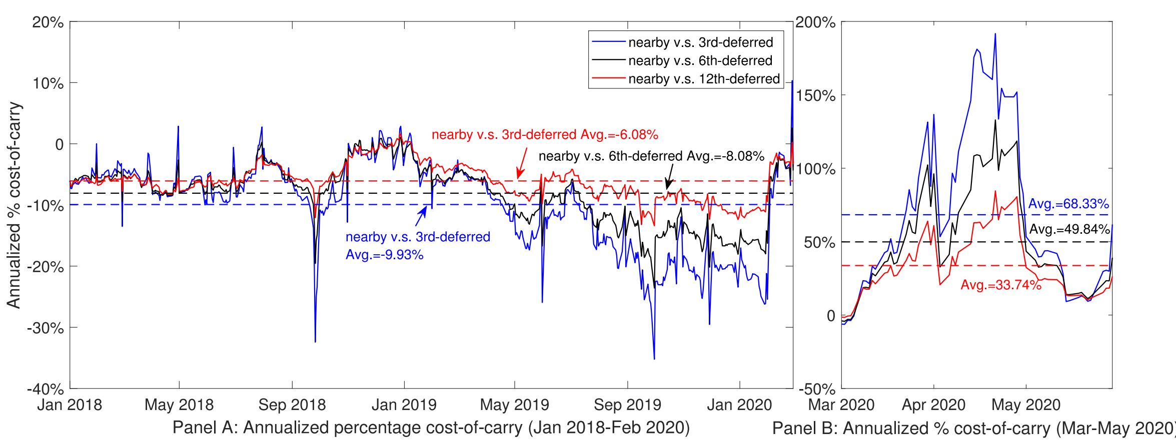
[4] We conduct an ARCH effect test with the Lagrange Multiplier (LM) method proposed by Engle (1982) for each estimation window, and 32 of 36 Chi-square statistics show that the null hypothesis – no ARCH effect in residuals – is strongly rejected at least 5% significance level. Hence, we use a market model with a GARCH (1,1) specification to assess the abnormal returns. The results are still generally similar without the GARCH (1,1) specification operating. We thank an anonymous reviewer for this suggestion.



(a) Annualized percentage cost-of-carry: WTI crude oil futures.



(b) Annualized percentage cost-of-carry: Brent crude oil futures.



(c) Annualized percentage cost-of-carry: Oman crude oil futures.

Fig. 2. Daily annualized percentage cost-of-carry: January 2018 to May 2020. *Notes*: Fig. 2 shows the daily annualized percentage cost-of-carry of three crude oil futures markets from January 2018 to May 2020. Nearby, third-deferred, sixth-deferred, and twelfth-deferred futures are used with the nearby futures price assumed as an unbiased proxy of cash price. The annualized percentage cost-of-carry is calculated as the slope of term structure adjusted by the difference between time-to-maturity of two futures contracts, i.e., $(F_2 - F_1)/F_1 \times [365/(D_2 - D_1)] \times 100\%$, where F_1 and F_2 respectively denote the nearby and deferred futures, while D_1 and D_2 denote the how many trading days until the expiration days of nearby and deferred futures, respectively. The market is in contango if the annualized percentage cost-of-carry is positive, otherwise the market is in backwardation. The full sample is split into two sub-samples: January 2018 to February 2020 and March 2020 to May 2020, where results are shown in Panel A and Panel B, respectively. The WTI negative futures price took place on April 20, 2020 is not considered in the calculation. The dashed lines denote the average levels of three cost-of-carry series with the average values shown in the same colors as the lines. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

summation of the obtained ARs in the time interval; namely,

$$AR_{it} = R_{it} - \left(\hat{\alpha}_i + \hat{\beta}_i R_{mt}\right), \text{for } \forall t \in \left[T_2 + 1, T_3\right],$$
$$CAR_i\left(\tau_1, \tau_2\right) = \sum_{t=\tau_1}^{\tau_2} AR_{it}, \tag{7}$$

where $T_2 + 1 \leq \tau_1 \leq \tau_2 \leq T_3$. Now, we calculate average cumulative abnormal return (CAAR) by taking the mean of $CAR_i\left(\tau_1, \tau_2\right)$ over N markets in the considered time interval, viz.,

$$CAAR\left(\tau_1, \tau_2\right) = \frac{1}{N} \sum_{i=1}^{N} CAR_i\left(\tau_1, \tau_2\right). \tag{8}$$

To examine whether the events affect the markets or the presence of CAARs, we focus on the following null and alternative hypothesis:

$$\boldsymbol{H_0} : CAAR = 0,$$
$$\boldsymbol{H_1} : CAAR \neq 0. \tag{9}$$

The null hypothesis indicates that no CAAR is statistically significant, and thus the events do not have significant impacts on the markets. However, if the null hypothesis is rejected, this reveals that the events have statistically significant impacts on the markets and, consequently, a nonzero CAAR. We include both "negative" and "positive" events, which correspond to the outbreak and truce of the oil price war, respectively. Generally, market participants are likely to be confident when positive news comes to the market, while the opposite is true when negative news arrives. Hence, following this logic, the oil price war may cause positive impacts on the markets as well as negative ones; the CAARs may not always be negative, and are likely to become positive when some good signs/news of the truce arrive. Thus this paper may differ from some other studies (e.g., Pozo and Schroeder, 2016) that solely investigate negative events, such as food recalls that usually have negative effects on food firm's reputation.

To test the significance of the calculated CAARs, similar to Pozo and Schroeder (2016), a clustering issue may arise because event windows overlap in calendar time. In this study, we may find a total clustering – that is, the same event may occur on the same day for a number of markets (MacKinlay, 1997). Hence, we use a relatively strict t-statistic proposed by Kolari and Pynnonen (2010) to test the statistical significance of calculated CAARs. It modifies the one proposed by Boehmer et al. (1991) and considers the standardized residuals corrected for event-induced changes in volatility and cross-correlation. If the t-statistic is statistically significant at a given level, we can say that the event has a significant impact on crude oil markets on average. Since the issue of clustering does not affect CARs, we adopt the Patell t-statistic (Patell, 1976), which considers standardized residuals.

4. Data

In this study, we evaluate the effects of the oil price war on both crude oil futures and spot markets. Three futures and spot markets are considered: U.S. West Texas Intermediate (WTI, ticker: CL), European Brent (ticker: B), and Oman crude oil (ticker: OQD), which are benchmarks for the U.S., Europe, and the Middle East, respectively. For futures prices, we focus on WTI crude oil futures traded on the NYMEX, Brent crude oil futures traded on the Intercontinental Exchange (ICE), and Oman crude oil futures traded on the Dubai Mercantile Exchange (DME). As noted in Section 2, the term structure of crude oil futures has been in a deep contango since March 2020, whereby the nearby futures price is lower than the deferred futures prices. Following Demirer and Kutan (2010) and Buyuksahin et al. (2013) to evaluate how the price war affects futures contracts at different time horizons, we collect daily settlement prices for futures contracts with different time-to-maturity on each futures market. Specifically, we examine nearby, third-deferred, sixth-deferred, and twelfth-deferred futures contracts, which cover different time-to-maturity for up to one year. All of the crude oil futures contracts are monthly and expire prior to a delivery month.[5] We roll over the nearest delivery month contract to the second nearest one when the former expires. The daily settlement price of each futures contract is collected from Barchart.com. For the spot prices, we use the WTI crude oil spot FOB at Cushing, Oklahoma; the European Brent crude oil spot FOB; and the Oman crude oil spot. The first two prices are available on the U.S. EIA and the last is collected from the Wind Financial Terminal.[6] All prices are quoted in U.S. dollars per barrel. Motivated by Ramiah et al. (2019), we use the MSCI ACWI index as a proxy of the market index (i.e., R_{mt}) in Eq. (6).[7] The MSCI ACWI Index is able to represent 23 countries with developed markets and 27 emerging countries with developing markets, which is more suitable for covering the economies of both developed and developing countries in our study.

As we noted in Section 2, crude oil futures markets have witnessed a significant change in term structure, and the markets have been in a deep contango since March 2020. To further analyze how the term structure has changed, we calculate the annualized percentage cost-of-carry for different futures contracts, which consists of storage cost, risk-free interest rate, and convenience yield if any, with the results shown in Fig. 2. To ensure comparison, we annualize and scale the cost-of-carry calculated. The annualized percentage cost-of-carry is computed from the slope of the term structure adjusted by the difference between time-to-maturity of nearby and deferred futures.[8] Here, the nearby futures price is assumed to be an unbiased proxy for cash price. Generally, a futures market is in contango if the cost-of-carry is positive; otherwise, the market is backwardated. To enhance visualization and better demonstrate the structural change in the term structure, we report the calculated cost-of-carry for two subperiods: one from January 2018 to February 2020 – which is approximately the pre-pandemic period – and the other from March 2020 to May 2020, which is roughly the in-pandemic period. It is noteworthy that the negative crude oil price that occurred in the WTI crude oil market is not considered, since it violates a general assumption that commodity prices are positive; in particular, it would not reflect the actual price relationships between nearby and deferred futures if the cost-of-carry was calculated.

As shown in Fig. 2, we can observe that all crude oil markets are generally backward in our sample, with 350 (56.27%); 447 (69.41%); and 532 (82.61%) trading days showing negative daily cost-of-carry in the WTI, Brent, and Oman markets, respectively. It is obvious that all of the markets experienced a dramatic increase in cost-of-carry, from average magnitudes of −3.87% (−\$2.34) to −1.80% (−\$1.09); −5.47% (−\$3.68) to −4.46% (−\$3); and −9.93% (−\$6.59) to −6.08% (−\$4.04) for the first subsample, to those of 38.56% (\$10.13) to 85.09% (\$22.35); 32.92% (\$10.19) to 63.98% (\$19.81); and 33.74% (\$10.34) to 68.33% (\$20.94) for the second subsample in the WTI, Brent, and Oman markets, respectively. This means that the markets are in a contango from a general backwardation, and a trader must pay at least 30% more than the nearby price on average to store crude oil for selling in the future, regardless of how long the storage is. The huge demand drops amid the pandemic and the limited storage capacity result in difficulties related to physical delivery, and cause a large cost-of-carry for a trader who intends to arbitrage through the calendar spread as well. Furthermore, the WTI market is in the deepest contango

[5] Specifically, the NYMEX WTI futures contract expires 3 business day prior to the 25th calendar day of the month prior to the contract month and 4 business days prior to the 25th calendar day if it is not a business day. ICE Brent crude oil futures and DME Oman crude oil futures expire on the last business day of the second month prior to the contract month.

[6] Data are available at the U.S. EIA website (https://www.eia.gov/).

[7] Data are available at the MSCI website (https://www.msci.com/acwi).

[8] Specifically, the annualized percentage cost-of-carry is formularized as $\left(F_2 - F_1\right)/F_1 \times \left[365/\left(D_2 - D_1\right)\right] \times 100\%$, where F_2 and F_1 denote the deferred and nearby prices, respectively, while D_1 and D_2 denote how many trading days until the expiration days of nearby and deferred futures, respectively.

generally among all crude oil markets, with an average of 85.09% cost-of-carry between nearby and third-deferred futures, whereas the cost-of-carry of Brent and Oman futures is roughly two-thirds that in WTI market on average. According to Fattouh and Imsirovic (2020), this can be explained by how flexible the delivery procedure is in the three markets. The WTI futures contract is restricted to inland storage facilities and pipelines in Cushing, Oklahoma; the storage capacity there has reached nearly 500 million barrels, approaching the record high of March 2017. However, both Oman and Brent crude oil futures have greater access to storage through more flexible storage capacity, such as shore tanks and shipping or floating storage, which diffuses the storage pressure on crude oil to some extent, and helps to relieve the pressure on the upward cost-of-carry.

5. Empirical results

5.1. Impact of the outbreak

The calculated CAARs during the outbreak of the price war are depicted in Fig. 3. For the sake of concision, the statistical significances of the CAARs are reported in Table A1 in online supplementary Appendix A. In general, it is noteworthy that most statistically significant CAARs occur before the price war broke out, whereas the CAARs after the outbreak are not statistically significant for most futures and spot returns. Most CAARs calculated in event windows [−2, 15] and [−1, 15] are statistically significant and their absolute values are larger than those in the other two event windows. We should note that the calculated average normal returns are cumulative, and the negative average normal returns observed before the outbreak are not offset; however, those become positive after the sixth trading day. This strongly suggests that material impacts began before the price war broke out and that the outbreak itself did not have a large impact, supporting the hypothesis regarding information leakage. Specifically, all futures returns experience significant declines within 6 trading days, then rebound on the seventh trading day after the price war began. Hereafter the values in parentheses below are the CAARs when considering 2-day information leakage. On average, for nearby futures, the crude oil return drops by 13.50% (42.58%) within 6 trading days and declines by 27.17% (56.25%) within 15 trading days after the price war began. With regard to the third-deferred futures, the crude oil return on average reduces by 3.58% (27.34%) within 6 trading days and still continues to decline, by 1.95% (25.70%), within 15 trading days after the war started. Similar patterns could also be found in sixth- and twelfth-deferred futures, but the impacts on them are smaller. For example, the sixth-deferred futures return on average slightly increases by 0.25% (still drops by 20.33%) within 6 trading days after the war began and increases by 5.16% (still declines by 15.41%) within 15 trading days. As for the spot markets, the CAARs decrease gradually and the impacts are much larger than those in the futures markets. Indeed, the return in the spot markets on average reduces by 17.69% (48.97%) within 6 trading days and continuously declines by 46.40% (77.69%) within 15 trading days. Our findings indicate that market participants were able to perceive and assimilate potential change with respect to the forthcoming conflicts between Saudi Arabia and Russia before the price war actually broke out. Potential reasons may be as follows. Crude oil is a vital national strategic resource and is also one of the most actively traded commodities, which attracts many market players and has been widely used for risk management and speculation (Fattouh and Imsirovic, 2020). Moreover, Russia's refusal to participate in the production decrease was not helpful for stabilizing the market price, which may have exacerbated the bearish markets and spread pessimistic sentiment across markets. Thus, when negative news came before the war broke out, market participants were likely to be pessimistic about the market performance in the future; some may liquidate their futures positions quickly, or adjust the weight of crude oil futures in their portfolios if necessary. Similarly, producers may change their current production schedule and adjust their hedge strategy in the futures markets to react to bearish market fundamentals. All of these could put the downward pressure on crude oil prices, resulting in negative impacts before the war broke out.

Futures contracts with different time-to-maturity react to the outbreak of the price war differently. When the price war broke out, nearby and spot returns generally experience relatively large impacts that persist to the end of the event window. However, backdated futures contracts are not influenced as severely, and the impacts disappear about one or two trading days after the outbreak. For the futures markets, the nearer a contract's maturity is, the larger impact the it would experience. This finding is consistent with Demirer and Kutan (2010), who investigate how nearby futures and deferred futures react to OPEC and SPR announcements, and suggest that deferred futures suffers from fewer impacts as the futures maturity extends further. The reason for this could be attributed to the high storage cost and low spare storage capacity under the bearish market. The low spare storage capacity and corresponding increasing storage cost negatively influences the desirability of delivering crude oil in Cushing for traders who hold expiring futures positions. In contrast, the limited storage capacity in Cushing should matter less for backdated futures contracts, since they are not supposed to make immediate delivery. Our illustration is similar to that of Buyuksahin et al. (2013), who focus on a large spread of WTI and Brent crude oil futures starting in the fall of 2008, when Cushing land storage capacity was in congestion. In addition, the outbreak of the price war generally impacts crude oil spot markets the most. Since the spot market is used to make immediate delivery, the sluggish demand is more likely to affect the market in which traders can purchase crude oil the easiest. Generally, spot markets are not as highly competitive as futures markets, and thus more exposures may exist in a spot market than in a futures market; it is hard to manage risk solely with spot markets, which indicates that spot markets have less resilience than futures markets.

For impacts on individual markets, we report CARs for each futures and spot market in the event window [−2, 15]. The results are shown in Fig. 4. The statistical significances of the CARs are also presented in Tables A2-A4 in online supplementary Appendix A. Similar to the patterns of the CAARs across markets, each futures return undergoes significant decreases within 6 trading days, in which nearby futures returns reduce by 30%-60% within 6 trading days and the magnitude of the impacts is negatively correlated with the time-to-maturity. For instance, the twelfth-deferred futures return reduces by 5%-25% within 6 trading days, which is half or less than that of the nearby futures returns. According to Tables A2-A4, we find that most CARs are statistically significant on both post-event days and the event day, which indicates that in addition to the information leakage that takes place before the event, the event also affects the market. Finally, Fig. 4 also confirms that the backdated futures suffer from the oil price war less, which is consistent with what we find in the scenario of average impacts measured by the CAARs.

5.2. Impact of the truce

The calculated CAARs during the truce are depicted in Fig. 5 and their statistical significances are reported in Table B1 in online supplementary Appendix A. We note that the negative prices that occurred in WTI crude oil markets on April 20, 2020, create some difficulties in calculating daily log-returns. To address this issue, we use two kinds of returns. We use the log-returns but remove the data for both the day with negative price and the next day (i.e., April 20, 2020 [+6] and April 21, 2020 [+7]). The other is the one-period simple return, which calculates the returns as $\left(op_t - op_{t-1}\right)/op_{t-1}$, is applied in both the nearby futures [F1(S)] and the spot market [Spot (S)].

Much as in the outbreak of the price war, information leakage is statistically significant before the truce, as indicated by the CAARs

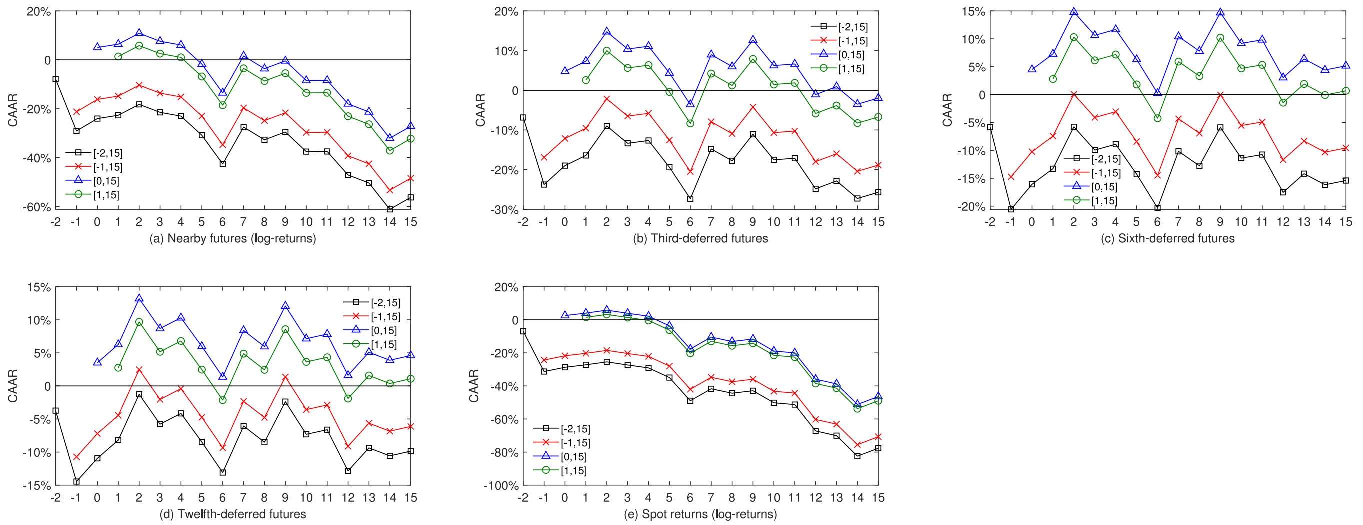


Fig. 3. Cumulative average abnormal returns (CAARs): Outbreak of the oil price war. *Notes*: The horizontal axis represents τ_2, the ending point of each event window. CAARs in four event windows are calculated: [−2, 15], [−1, 15], [0, 15], and [1, 15].

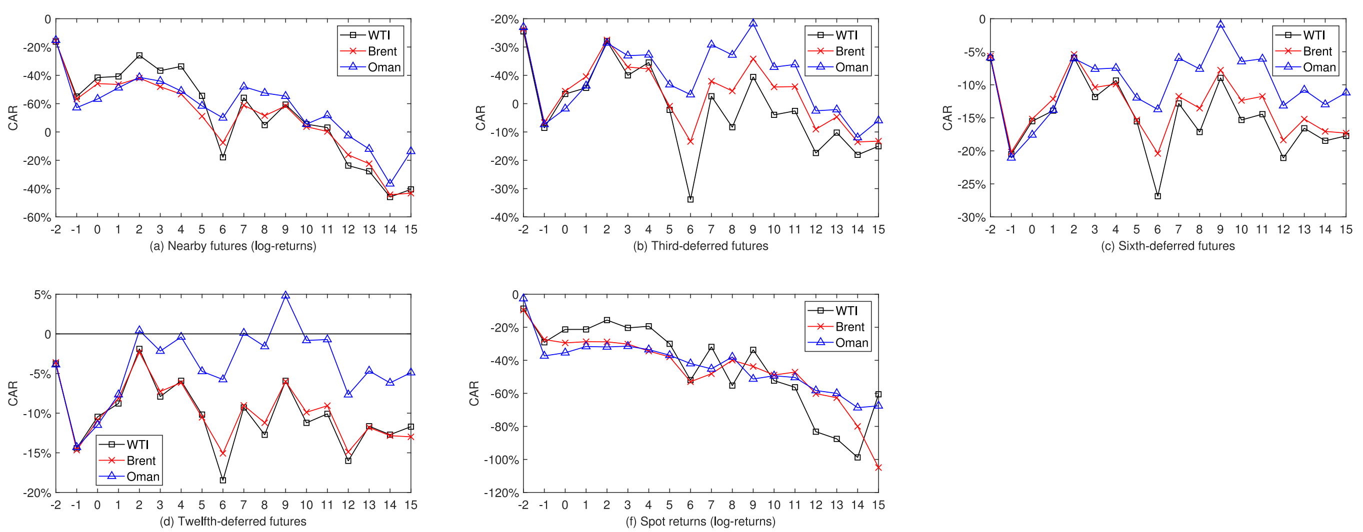


Fig. 4. Cumulative abnormal returns (CARs): Outbreak of the oil price war. *Notes*: The horizontal axis represents τ_2, the ending point of each event window. CARs in four event windows are calculated: [−2, 15], [−1, 15], [0, 15], and [1, 15].

becoming positive. Thus, this corroborates that through broad international mediation and intervention, market participants were likely to have positive expectations of the markets and that a final reconciliation between the two major producers could be achieved. Some market participants might wait and see what would happen in the future and held their previous trading strategies rather than rapidly exiting the markets. Generally, the truce did result in positive abnormal returns before the war ended. Nevertheless, compared with the scenario of the outbreak, these short-time positive abnormal returns finally are offset by the subsequent negative ones, in both futures and spot markets. Moreover, the price war's outbreak and truce affected the markets asymmetrically, where negative impacts generated by information leakage during the outbreak are generally more durable than the positive ones it generated during the truce. This also reveals that some positive news during the truce, such as the U.S. mediation occurring before the truce, were not strong enough to completely reverse their preexisting negative views of the markets. Indeed, although market participants could adjust their expectations, the bust economic environment was unlikely to change in a short period of time and, at the same time, panic regarding physical delivery spread in the markets, which was also a driver of the negative price in the WTI. Furthermore, this result also shows that market participants reacted to the outbreak and truce differently, and negative news threatened them more than positive news. Thus, most CAARs remain below zero after the truce, as shown in Fig. 5 (a). In addition, the CAARs for futures markets decline within 7 trading days after the truce, then increase until the end. Hereafter, we report the CAARs in parentheses below when considering 5-day information leakage. For nearby futures log-returns, for example, on average, the crude oil return reduces by 41.76% (28.80%) within 7 trading days after the truce, then increases to almost −6.75% (−5.28%) by the end of the event window. According to Fig. 5 (c)-(e), we find that the further a contract's expiration, the smaller its impact, which is similar to which impacts are negatively correlated with the futures time-to-maturity with respect to the outbreak of the war.

The above analyses are based on log-returns, which removes negative prices. Fig. 5 (b) reports the results with simple returns. It is obvious that negative prices hit global crude oil severely, in which a dramatic fall of crude oil returns can be observed 5-7 trading days after the truce. The CAARs within 7 trading days after the truce reach −179.80% (−164.05%) from −9.44% (6.30%) on the truce date, and then increase steadily to −136.13% (−117.10%) in the end. As for spot markets, the patterns are generally similar to those of nearby

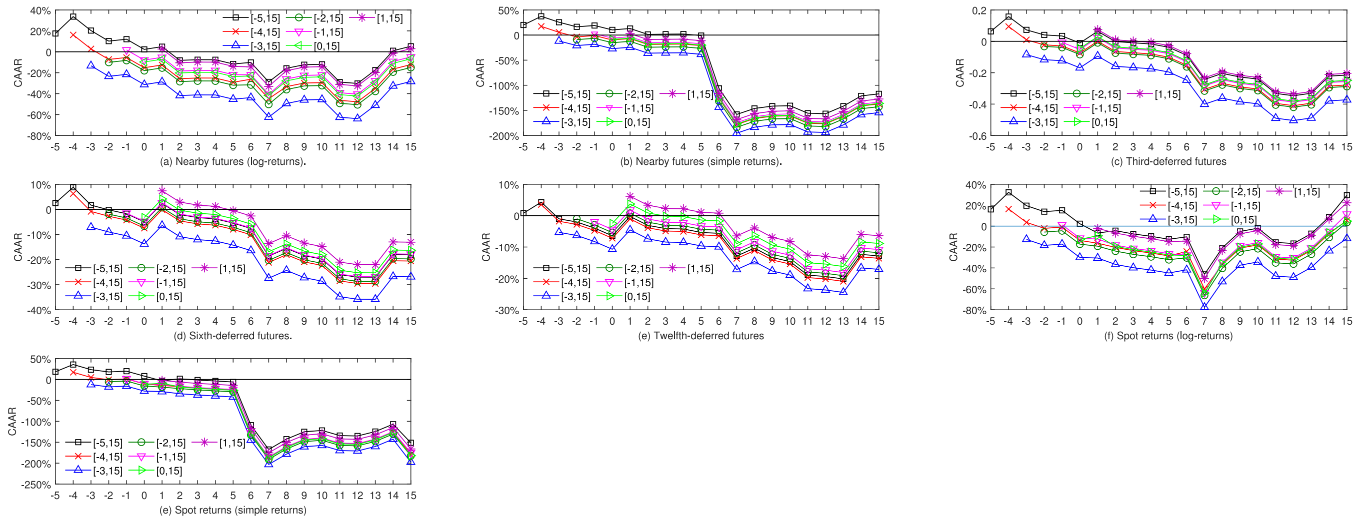


Fig. 5. Cumulative average abnormal returns (CAARs): Truce of the oil price war. *Notes*: The horizontal axis represents τ_2, the ending point of each event window. CAARs in seven event windows are calculated: [−5, 15], [−4, 15], [−3, 15], [−2, 15], [−1, 15], [0, 15], and [1, 15]. The negative WTI crude oil futures and spot prices that occurred on April 20, 2020 are not considered in the scenario of using the log-returns of the nearby futures, but they are considered when using the simple returns of the nearby futures.

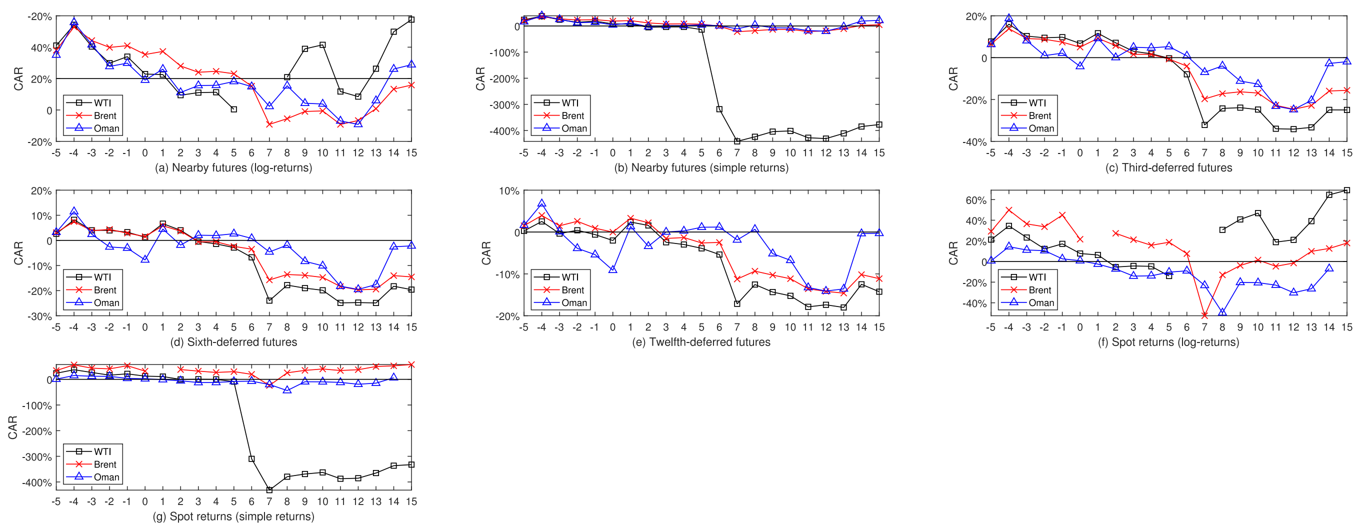


Fig. 6. Cumulative abnormal returns (CARs): Truce of the oil price war. *Notes*: The horizontal axis represents τ_2, the ending point of each event window. CARs in seven event windows are calculated: [−5, 15], [−4, 15], [−3, 15], [−2, 15], [−1, 15], [0, 15], and [1, 15]. The negative WTI crude oil futures and spot prices that occurred on April 20, 2020 are not considered in the scenario of using the log-returns of the nearby futures, but they are considered when using the simple returns of the nearby futures. No log-returns could be calculated on April 20, 2020 (τ_2 = 6) and April 21, 2020 (τ_2 = 7) in WTI crude oil futures and spot markets. No data are available in Brent crude oil spot market on April 10, 2020 (τ_2 = 1), and in Oman crude oil spot market on May 1, 2020 (τ_2 = 15).

futures with simple returns (F1(S)). The crude oil spot return on average reduces by 187.14% (167.29%) within 7 trading days after the truce, then increases to −182.14% (−151.23%) at the end of the event window. Interestingly, the negative crude oil prices seem not to affect the markets on average, since some corresponding CAARs are not statistically significant, regardless of crude oil futures or spot markets.

With regard to individual markets, we depict calculated CARs for event window [−5, 15] in Fig. 6 and their statistical significance in Tables B2-B4 in online supplementary Appendix A.[9] In general, the results for individual markets are more mixed than those we obtain in the outbreak. For each individual market, the impacts during the truce are generally smaller than those of the outbreak without considering negative prices. It is obvious that the negative price of WTI futures indeed hit the WTI crude oil markets severely, and the return reduces significantly by more than 400% with simple returns, compared with the normal returns that should have been achieved. However, this extreme abnormal return is not observed in the Brent and Oman crude oil markets. For WTI futures contracts, the NYMEX specifies that all physical crude oil must be delivered from pipelines and storage facilities solely in Cushing, Oklahoma; which is less flexible than the delivery methods in Brent and Oman futures markets, in which shipping and floating storage can be considered in addition to inland method. Hence, long traders in the WTI futures market are more urgently motivated to

[9] Due to the negative crude oil prices in WTI crude oil markets, we do not report CARs for F1 (L) and Spot (L) in 6th and 7th trading days after the truce (i.e., +6 and +7) while the F1 (S) and Spot (S) consider the negative prices. Since there is no data in the Brent crude oil spot market on April 10, 2020, we do not report corresponding CARs for the 1st trading day after the truce (i.e., +1) for Spot (L) and Spot (S). The same situation occurs in the Oman crude oil spot market: no data is released in the 15th trading day after the truce (i.e., +15).

close their positions than those in the other two markets, because it is harder for them to find available storage slots even if are willing to accept physical delivery. In addition, Brent futures have shifted the fundamental oversupply to some alternative financial instruments, such as Dated Brent and Brent complex, which supported this crude oil benchmark to perform well. Similarly, most CARs are statistically significant before the event date, which indicates that information leakage still operates in each individual market. When comparing all futures and spot returns in each individual market, it is not hard to see that in general, spot markets suffer from more impacts than futures markets. In addition, the conclusion that the impacts are negatively correlated with futures time-to-maturity is still robust.

5.3. Summary

In sum, the following conclusions are noteworthy: (a) Information leakage is statistically significant for both the war's outbreak and truce, and market participants are able to perceive and assimilate the market changes. (b) The outbreak and truce have asymmetrical impacts on the markets and negative news threatens the market participants more than positive news, with the information leakage considered. (c) For futures markets, the impact generated by the oil price war is negatively correlated with the time-to-maturity. (d) In general, the negative crude oil prices severely affect only WTI crude oil markets, but do not influence crude oil markets on average.

6. Conclusions

The COVID-19 pandemic has changed global crude oil markets. Restrictive orders to contain the novel coronavirus (SARS-CoV-2) have created sluggish demand for crude oil, and the resulting crude oil glut has caused high storage costs. This has led to a significant change in the term structure in futures markets from a general backwardation to a contango, with the annualized percentage cost-of-carry spiking to above 100%. This paper uses an event study approach to analyze how the Russia-Saudi Arabia price war influenced global crude oil markets. Three major crude oil markets–West Texas Intermediate (WTI), Brent, and Oman are considered in this study. The nearby, third-, sixth-, and twelfth-deferred futures returns are used with the "roll yield" excluded when rolling over futures contracts, which could stretch our analysis to a one-year-forward horizon and keep our returns are historically realized. We also investigate the impact of the negative crude oil prices triggered in both the WTI futures and spot markets on April 20, 2020. We use the one-period simple return to calculate the daily returns to overcome an issue of which the natural logarithmic function defines in positive real numbers. Meanwhile, we also apply the log-returns that remove the negative crude oil prices to compare with results that consider the negative prices.

The findings indicate that information leakage before the event dates plays an important role in the war. This suggests that market participants could perceive and assimilate new information in the markets, thus restraining the corresponding impacts that should have occurred within the oil price war. Furthermore, the outbreak and truce impacted the markets asymmetrically, and negative impacts generated from information leakage during the outbreak are more durable than the positive ones it generated during the truce. In addition, with regard to futures markets, the impact generated by the oil price war is negatively correlated with the futures time-to-maturity; that is, the nearby futures undergoes the largest impacts and the twelfth-deferred futures experiences the smallest ones. This could be attributed to the fact that the high storage cost and limited spare storage capacity (not only in Cushing) would most influence traders who hold positions of expiring futures contracts to deliver crude oil, and should matter less for backdated futures contracts, since they are not delivered immediately. The obtained results suggest that the negative crude oil prices do not affect global crude oil markets on average, but they substantially influence the WTI crude oil futures and spot markets soley in that the WTI futures contract restricts the physical crude oil in the pipelines and storage facilities in land, which causes a loss of flexibility compared with the Brent and Oman crude oil contracts, where shipping and floating storage are available. Additionally, traders' inexperience with physical delivery could also trigger the panic that caused them to liquidate their positions.

The oil price war substantially shocked the energy sector, and some implications are notable. The shrinking demand could put significant pressure on some downstream enterprises, such as refineries. According to the EIA (2020a), in mid-April 2020, U.S. refinery runs fell to 12.8 million/bpd, 24% less than the same time the previous year. Moreover, the net profit loss of oil companies was also significant. For example, Royal Dutch Shell announced a record net profit loss of −$21.7 billion in 2020, which is the first time it had experienced a negative net profit (BBC, 2021). In addition, the recession in the oil sector may negatively influence the performance of U.S. refineries in stock markets and affect their ability to invest in the future as well. Indeed, the world's major oil companies, such as Exxon Mobil and Royal Dutch Shell, have witnessed the sharpest decreases in stock prices for decades. For instance, Exxon Mobil's stock price dropped by about 55.64% ($40) from January to March 2020, which is the largest price fall in its history. The huge depreciation has also resulted in dividend cuts for oil companies. Royal Dutch Shell cut its dividend for the first time since World War II, with a 46% plunge in first-quarter net income at the end of April 2020 (BBC, 2020c). Moreover, due to the containment measures of the pandemic and downward pressure on operations, job losses were inevitable during the pandemic. BP announced plans to cut 10,000 jobs in June 2020, and about 10% of Royal Dutch Shell employees lost their jobs (BBC, 2020a). However, the recession in the oil sector also motivated oil companies to adopt new technologies, such as artificial intelligence, to improve decision-making and reduces business risks, with the help of the huge volume of raw data they already possessed and the growth of data management (Koroteev and Tekic, 2021). It is worth noting that the pandemic has also impacted the U.S. shale oil industry. U.S. oil production capacities have almost doubled since 2012 due to the shale oil revolution, and this has challenged the world oil order that OPEC established. However, the cost of U.S. shale oil is generally higher than conventional crude oil, partly because of the relatively higher cost of hydraulic fracturing technology.[10] Hence, the low crude oil price triggered by both the pandemic and the oil price war is a negative signal to some U.S. shale crude oil enterprises. Indeed, U.S. shale oil sectors have experienced an unviable period and required a breakeven price of between $50 and $55 per barrel – a level that seemed impossible for crude oil prices to rapidly reach during the pandemic (CNBC, 2020). However, not everyone is a loser in the price war; some big oil importers are likely, theoretically, to benefit from the oil price fall and, if possible, replenish their storage capacity (BBC, 2020d).

To conclude, we would like to state some limitations of this study and suggest directions for future research. First, we restricted our attention to global crude oil markets; however, the oil price war also affected other energy markets. Thus, it would be worthwhile to determine how the war influenced them and whether the nexus between crude oil and other energy products, such as natural gas, and heating oil, has changed. Future research might also analyze whether the war influenced energy firms in equity markets, because their performance in equity markets is related to their cash flows, which also influences their profitability. Second, partly because of the limits of our methodologies, we restricted our attention to how the oil price war affected the crude oil markets in our sample period, whereas some other factors may have also influenced the markets. Hence, it would valuable to

[10] Estimated production costs of various petroleum products can be found at https://www.e-education.psu.edu/eme801/node/484.

examine whether or how other factors affected the markets. Third, future research related to negative prices, such as price comovement and volatility spillover inclusive of the negative price (e.g., Corbet et al., 2020), is warranted. These three directions will be pursued in our future research agenda.

CRediT authorship contribution statement

Richie Ruchuan Ma: Methodology, Software, Formal analysis, Investigating, Writing – original draft. **Tao Xiong:** Conceptualization, Resources, Writing – review & editing, Supervision, Funding acquisition. **Yukun Bao:** Validation, Writing – review & editing, Project administration.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eneco.2021.105517. The online supplementary materials report the statistical significances of both CAARs and CARs.

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